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TECHNICAL NOTE

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AN EXPERIMENTAL STUDY OF THE EFFECT OF DOWNWASH FROM A TWIN-PROPELLER VTOL AIRCRAFT ON SEVERAL TYPES OF GROUND SURFACES

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AN EXPERIMENTAL STUDY OF THE EFFECT OF DOWNWASH FROM A TWIN-PROPELLER VTOL AIRCRAFT ON SEVERAL TYPES OF GROUND SURFACES

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SUMMARY

A full-scale, twin-propeller VTOL aircraft with a maximum gross weight of 3,400 pounds has been operated on the ground to study the effect of downwash on several types of ground surfaces.

Static operation over loose snow indicated a zone of obliterated vision ahead of the pilot in an arc of approximately 10° on each side of the plane of symmetry. An arc 10° to 45° each side of the center line was found to be an area of fair visibility while the arc from 45° to 90° was an area of poor visibility.

Static operation in the presence of loose surface material indicated that the downwash cleared the area near the aircraft of these particles without recirculation or damage to any components.

Short-time operation at moderate forward speed over loose gravel, with the thrust axis at an angle of 70° from the horizontal, resulted in propeller-blade erosion and numerous small dents and fabric punctures in the sides of the fuselage. The propeller-blade erosion was superficial except for the leading edges where several layers of glass fiber were eroded.

INTRODUCTION

The energy developed by the slipstream of high-disk-loading VTOL aircraft presents an operational problem in hovering and in low-speed forward flight. When this flow strikes the ground and spreads out, it may, with increasing dynamic pressure, move loose particles on the ground surface and, in extreme cases, erode the ground. The movement of particles may result in visibility obscurement and possible damage to the VTOL aircraft. Considerable research on the general ground-erosion problem with models and small-scale VTOL aircraft has been reported in references 1 to 3. An analysis of damage to a twin-propeller VTOL aircraft during a taxi operation on a loose-gravel surface was reported in reference 4.

This report presents an experimental study of the movement of particles from several types of ground surfaces under the influence of a full-scale, twin-propeller VTOL aircraft operating on the ground. Operations at static conditions representative of hover and at moderate forward speeds on the ground are discussed. An assessment of damage to the blades and fuselage during operation at forward speed over a loose-gravel surface is also included. The tests reported herein are part of a general ground-erosion program being conducted with this aircraft by the Langley Research Center of the National Aeronautics and Space Administration.

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SYMBOLS

A	area of propeller disk, sq ft
D	diameter of propeller, ft
h	height of pitot-static tube from the ground, ft
q	dynamic pressure of outward-flowing sheet of air, lb/sq ft
q_{max}	maximum dynamic pressure of outward-flowing sheet of air, lb/sq ft
T	propeller thrust, lb
X	longitudinal axis through center line of aircraft
Y	lateral axis through center of rotation of propeller (normal to X-axis)
x	distance forward in plane of symmetry, measured from intersection of plane of symmetry and plane through axis of rotation of propellers, ft
y	lateral distance from center line of aircraft, ft
y_p	lateral distance from center line of aircraft to center of rotation of propeller, ft

APPARATUS AND PROCEDURE

The aircraft used in the investigation (fig. 1) was a twin-propeller VTOL aircraft powered by a single YT-53 engine; the maximum gross weight was 3,400 pounds. The propellers are driven from individual interconnected gear boxes mounted on the tips of a small-chord fixed wing. The nacelles are capable of tilting forward through an angle of 78° from the vertical.

L The propellers are three-blade configurations of 10-foot diameter
1 and are designed to maximize propeller normal force. The blades are
8 formed over a steel shank with foamed plastic and an outer layer of
3 glass fiber. All the blades were covered with a thin layer (0.020 inch)
7 of a urethane elastomer. Two blades on each propeller had a protective cover on the leading edge. One cover was made from a neoprene deicer boot and the other was a plastic sheet of flexible polyurethane. Photographs of a blade with a protected leading edge and of one without protection are shown in figure 2. The light chordwise area near the tip of the blade without leading-edge protection (fig. 2(b)) is bare glass fiber and is intended to assess the value of the plastic coating in the event of blade erosion. The blades are retained with a conventional hub; roll control is obtained from differential blade pitch which allowed different pitch angles for each propeller.

The nose, the cockpit area, and the upper half of the fuselage in the area of the engine compartment are covered with aluminum. The remainder of the fuselage is fabric covered. The small-chord fixed wing is covered with aluminum skin while the horizontal and vertical tails are fabric covered.

The dynamic pressure flow field about the aircraft was surveyed to determine the environment that would exist during subsequent tests over various ground surfaces. The plane of the propellers was parallel to the ground and located 1 propeller diameter above the gound. The dynamic pressures were measured as described in reference 5. For measurements where height was of little concern a hand-held pitot-static tube was utilized.

Static tests to study the movement of loose particles were performed by taking the aircraft to the test sites rather than attempting to bring the soil conditions to the aircraft. The aircraft was generally restrained during the tests with tie downs at three points attached to steel screw anchors in the ground. The test at forward speed was conducted on a runway overrun area which consisted of a rough asphalt surface covered with small loose gravel.

RESULTS AND DISCUSSION

The movement of particles under the influence of downwash is documented by observers' comments, still photographs, and 16-millimeter motion pictures. A motion-picture film supplement has been prepared and is available on loan. A request card form and a description of the film will be found at the back of this paper, on the page immediately preceding the abstract pages.

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Dynamic Pressure Environment

Measurements of the dynamic pressure of the outward flow of air from the propellers, reported in reference 5, are presented to indicate the pressure conditions to which the ground test sites would be subjected. The variation in dynamic pressure divided by the disk loading T/A with height above the ground at several locations along the two survey axes is presented in figure 3. The variation of the maximum dynamic pressure divided by the disk loading T/A measured along the X-axis and Y-axis is shown as a function of distance x/D or $\frac{y - y_p}{D}$ in figure 4.

Static Operation

Visibility.- A determination of pilot visibility was obtained from operation over a base of loose snow approximately 2 inches deep. The pilot reported a zone of obliterated vision in an arc of $\pm 10^\circ$ ahead of the airplane. An arc from 10° to 45° each side of the center line represented an area of fair visibility that the pilot reported as "operational with some restriction." The arc from 45° to 90° was an area of poor visibility.

The dynamic pressure existing at ground level in the right front quadrant of the VTOL aircraft was surveyed in an effort to understand these zones of relative visibility. The results of this survey are presented in figure 5 as lines of constant dynamic pressure divided by the disk loading that exists around the VTOL aircraft in this area. The zones of relative visibility noted by the pilot are also shown on the figure.

The area of obliterated vision is centered on the plane of symmetry and apparently results from the mixing of the flow and the gradual decay (as discussed in ref. 5) of the dynamic pressure with distance. The unsteady flow as well as the increased depth of the pressure profile is indicated in figure 4. Observers during the snow operation reported that a plume of snow shot forward and rearward on the plane of symmetry as power was applied to the engine.

The area of fair visibility exists in a region where the interaction of the flow from the two propellers results in the most rapid decay of the dynamic pressure with distance. Unpublished results from tests of a twin-propeller model operating over sand substantiate this; these results indicate that in this area, at a short distance from the model, the sand was undisturbed by the flow. Of course, the placement of the pilot about 1 diameter ahead of the propeller puts him in a position to look through a thinner region of disturbance in the area of rapid decay of dynamic pressure.

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The area of poor visibility is in a region where the decay of the dynamic pressure is more gradual, with a resulting large area of disturbance, but in contrast to the area on the plane of symmetry there is less mixing of the flow. The visibility is again influenced in this area by the pilot's location, inasmuch as he must look through a relatively thick curtain of distrubed ground material.

It appears that the flow field from the VTOL aircraft produces an area where visibility is classified as fair; however, this advantage could be eliminated unless the pilot is located some distance ahead of the center of rotation of the propellers. Model tests of a specific configuration would be necessary to determine the optimum location for the pilot.

<u>Movement of dirt and gravel</u>.- An indication of the motion of particles under the influence of downwash was obtained from operation of the aircraft over a relatively bare sandy-soil area surrounded by grass. At the time of the test the weather was warm and dry and the water content of the soil was 4.5 percent by weight. The wind was quartering on the nose at 8 to 12 knots with gusts to 20 knots. A photograph of the aircraft in place at the test site is shown in figure 6(a). The maximum disk loading during this test was approximately 20 lb/sq ft.

The fine sand on the surface was blown away starting at a disk loading of about 6 lb/sq ft and continuing throughout the test. The highest disk loading resulted in some erosion of the soil in the form of small clods of dirt; the size of the clods ranged up to a maximum equivalent to a disk of about 1.5 inches in diameter and 0.5 inch thick. A photograph showing the range of sizes of typical clods that were moved is presented in figure 6(b). The farthest any of these particles were moved was a distance of about 3.5 propeller diameters ahead of the axis of rotation. None of these particles were caught in the trap mounted on the engine air intake screen. A photograph of the intake screen (fig. 6(c)) indicates that only pieces of dry grass reached this area. There was no evidence that heavy particles struck either the propellers or the fuselage.

Further observations of the movement of particles under the influence of downwash are provided by operation on a naturally compacted fill area containing loose gravel ranging in size from 1/8-inch to 1-inch diameter. The wind was quartering on the nose at 10 knots. The weather was warm and dry; the soil contained 2 percent of water by weight. A photograph of the aircraft at the test site is presented in figure 7(a). Patches of the upper crust of the surface were peeled away at the maximum disk loading of 19 lb/sq ft. This result is illustrated in figure 7(b). The most obvious areas of peeling occurred where the tires of the aircraft had previously rolled over the ground. Other than in these areas, peeling occurred under the propeller (fig. 7(c)) and in a line on the ground generally coincident with the fuselage center line that appears to represent the path taken by the tail wheel as the aircraft was towed into position. This area is on the plane of symmetry between the two propellers where an upflow of the two meeting slipstreams exists. However, there was no visual or structural evidence that this material struck the underside of the fuselage. The entire area under the propellers and fuselage was swept clear of this eroded dirt and of the gravel apparent in figure 7(a). The largest accumulation of the swept dirt and gravel was along a line normal to the fuselage center line at a distance of about 3 propeller diameters ahead of and behind the center of rotation of the propellers. Some of this accumulation is illustrated in figure 7(d). There was no observable damage to the propeller blades or fuselage at the conclusion of this test.

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The motion pictures during this run, shown in the film supplement, showed that the dust cloud that was produced did not recirculate into the propellers. Observation, both visually and from the motion pictures, of the motion of eroded dirt patches and gravel indicated that this motion was primarily rolling and that vertical displacement occurred when the particles were deflected by the terrain or other objects in their path. None of the observable particles attained heights greater than 1 or 2 feet.

Operation at Forward Speed

A graphic indication of particle movement was obtained from operation at moderate forward speed over a runway overrun area. The surface base was rough asphalt covered with loose gravel ranging in size from about 1/8 inch to 1/2 inch in diameter. A photograph of the surface is presented in figure 8.

The aircraft was taxied slowly onto the overrun area for a distance of about 200 feet, turned around, and lined up for a run into the wind. The weather was warm and dry; the wind was quartering off the nose at 5 knots. A taxi run was initiated with the axis of rotation of the propellers tilted 70° from the horizontal. The run was made with the maximum power that could be used, consistent with the requirement that the aircraft remain solidly on the ground. This resulted in a static disk loading of about 13 lb/sq ft. The taxi run was initiated with these conditions and a speed of approximately 25 mph was attained as the aircraft cleared the overrun. The rolling time of the run was approximately 15 seconds. Color motion pictures taken with a 16-millimeter camera operating at 64 frames per second were utilized to study the runs. The motion pictures indicate that the aircraft in motion is continuously running through a cloud of particles. Individual particle movement, however, cannot be ascertained. This mode of operation was chosen to simulate the condition of VTOL operation where the aircraft is translated over the ground at very low altitude.

The motion of the particles is best determined from a study of the damage incurred by the aircraft during the test run. One propeller was painted white prior to the run to show the extent of the blade surface subjected to impact with the gravel particles. One blade showing this coverage for both camber and thrust faces is shown in figure 9. The impingement area on the camber face is confined to the leading edge while on the thrust face the leading edge and most of the outer two-thirds of the blade is covered. The damage to the blades was largely superficial. None of the impacts penetrated farther than the first layer of glass fiber except on the blade leading edges. The protective leading-edge strips were no more effective than the coating of the urethane elastomer. All leading edges had impacts located near the blade tips that penetrated one or more layers of glass fiber in isolated impacts. The one blade on each propeller where there was a chordwise strip of unprotected glass fiber sustained general erosion through several layers of glass fiber on the leading edge.

The area of the fuselage subjected to impact from the gravel was determined from holes in fabric and from paint removal and dents in metal areas. The extent of the area of maximum damage was approximately the lateral projection of the slipstream on the fuselage. A view of the fuselage in this area is presented in figure 10. The condition of the impacted surface indicated that the gravel struck with a flat horizontal trajectory normal to the fuselage, except for isolated impacts near the nose and tail that indicated a trajectory nearly parallel to the ground at a shallow angle with respect to the fuselage side.

The bottom of the fuselage showed no evidence of damage. Double-faced tape located under the fuselage as shown in figure 11 picked up sand-size particles during the test run. The amount of particles caught was again a maximum in the area of the lateral projection of the slipstream and decreased forward and rearward of this area.

The screened engine air intake with its catch trap is shown in figure 12. Gravel was collected in the trap, on the screen, and on the top of the fuselage. There was no evidence that the surrounding fuselage suffered any impact from the gravel. There was no damage to the remaining upper surface of the fuselage and the nose.

The motion pictures indicate that the aircraft is preceded by a cloud of disturbed material with a height about equal to that of the plane of the propellers. The accumulation of gravel on the nose of the fuselage and in and around the engine air intake screen without visible damage to the paint or the skin indicates that these are low-energy impacts of the cloud of disturbed material that the aircraft is running through. In contrast to this the material drawn through the propeller caused the damage noted on the propeller blades and the fuselage sides.

A difference was observed between the static tests and the operations at forward speed. During the static tests no particles of the size noted in the forward-speed tests were observed to attain heights as great as the plane of rotation of the propellers.

IMPLICATIONS OF RESULTS

The results of ground operation of a full-scale, twin-propeller VTOL aircraft, with a maximum gross weight of 3,400 pounds, suggests means of minimizing the visibility and damage problem arising from the action of the downwash on loose surface materials.

The presence of a zone of relatively good visibility in an arc from 10° to 45° each side of the plane of symmetry suggests that a VTOL aircraft should be able to be yawed in a hover operation to enable the pilot to survey the landing site for obstructions.

The results of static tests suggest that hovering-type landings and take-offs will minimize the problems of operation over ground surfaces covered with loose particles. Logically this might not appear practical since hovering in a wind is essentially the same as operation at forward velocity equal to the wind speed. However, moderate winds (in these tests there were gusts as high as 20 mph) will not blow the heavier loose particles back onto the aircraft. The effect of forward speed with the thrust axis at large angles from the horizontal results in the airplane running through the disturbance created ahead of it.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Air Force Base, Va., January 31, 1962.

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4. Pegg, Robert J.: Damage Incurred on a Tilt-Wing Multipropeller VTOL/STOL Aircraft Operating Over a Level, Gravel-Covered Surface. NASA TN D-535, 1960.

5. O'Bryan, Thomas C.: An Investigation of the Effect of Downwash From a VTOL Aircraft and a Helicopter in the Ground Environment. NASA TN D-977, 1961.

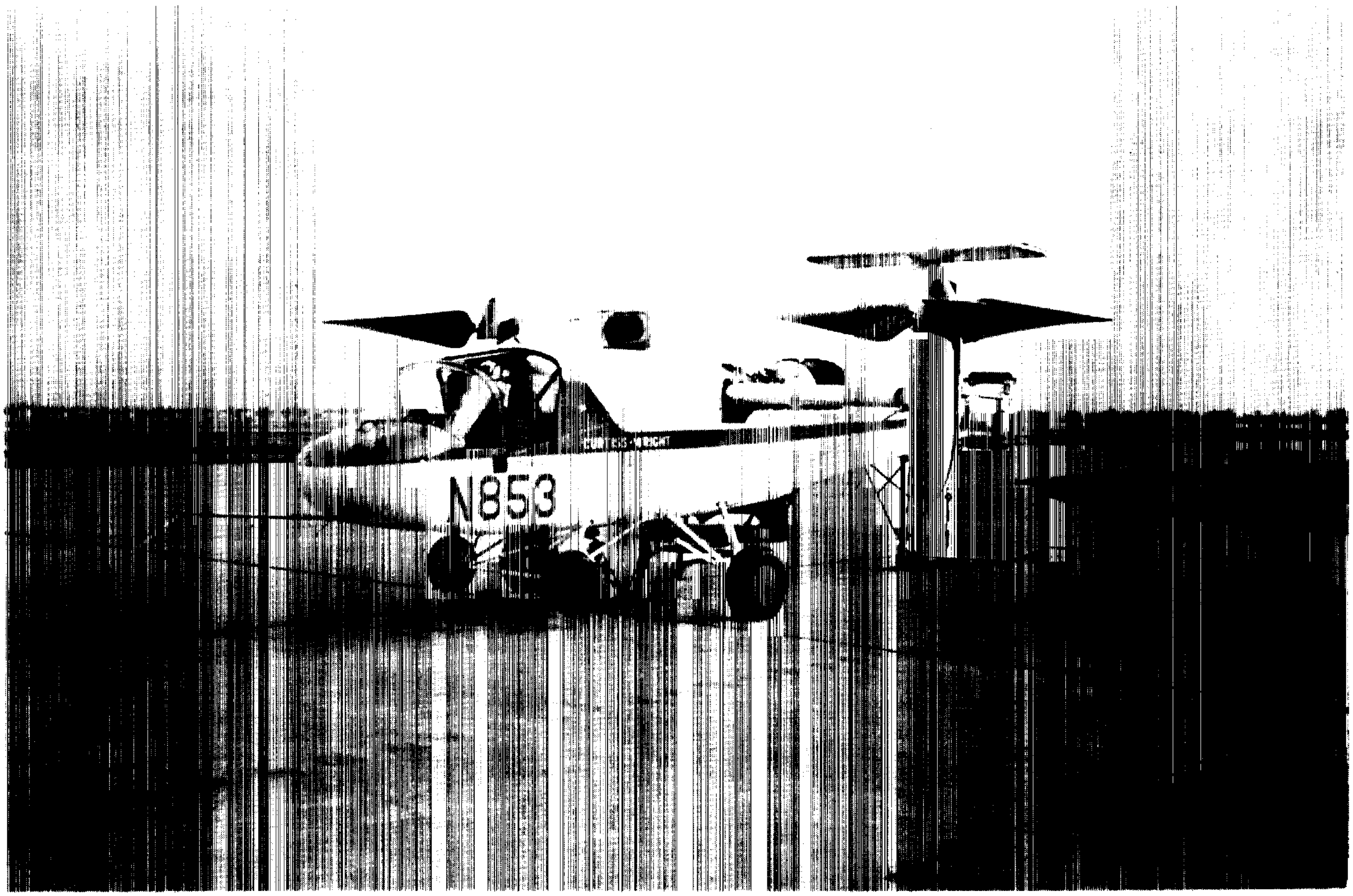

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Figure 1.- Photograph of VTOL aircraft used in study of effect of downwash.

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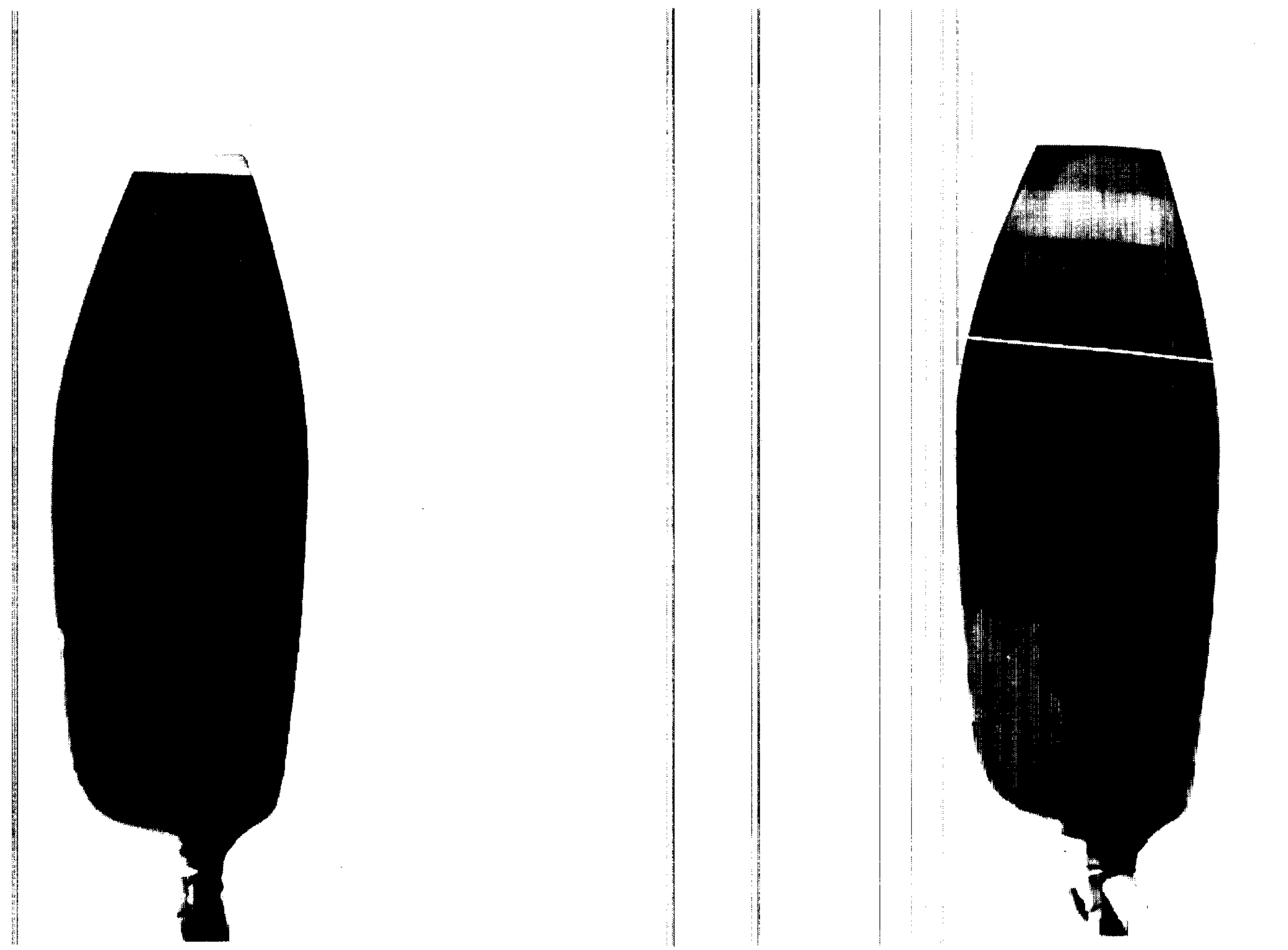

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(a) Protected leading edge.

L-61-513
(b) Unprotected leading edge.

Figure 2.- Photograph of typical propeller blades.

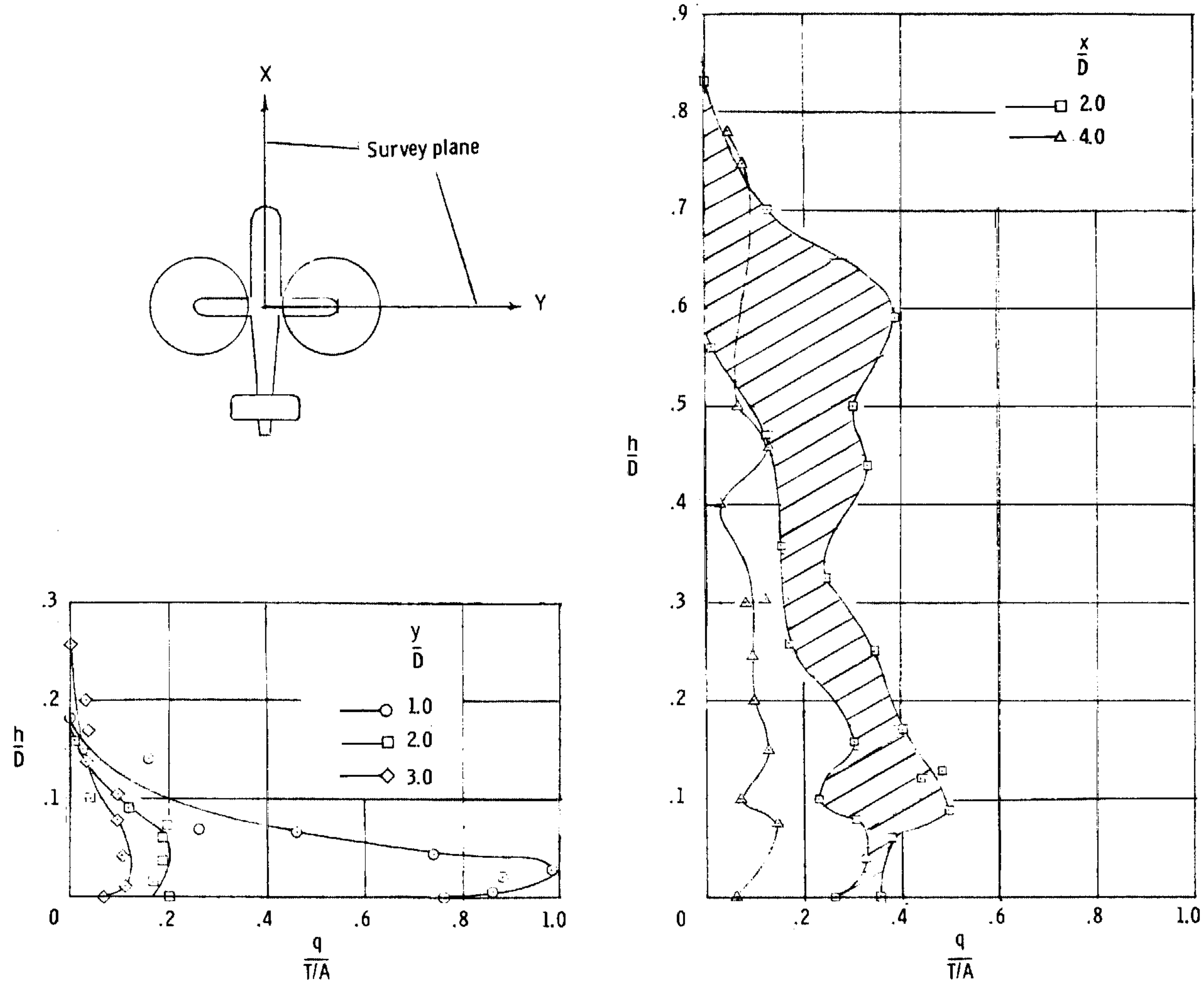

Figure 3.- Variation of dynamic pressure with height above ground for twin-propeller VTOL aircraft at several locations on plane of symmetry and on line normal to fuselage through center of rotation of propellers.

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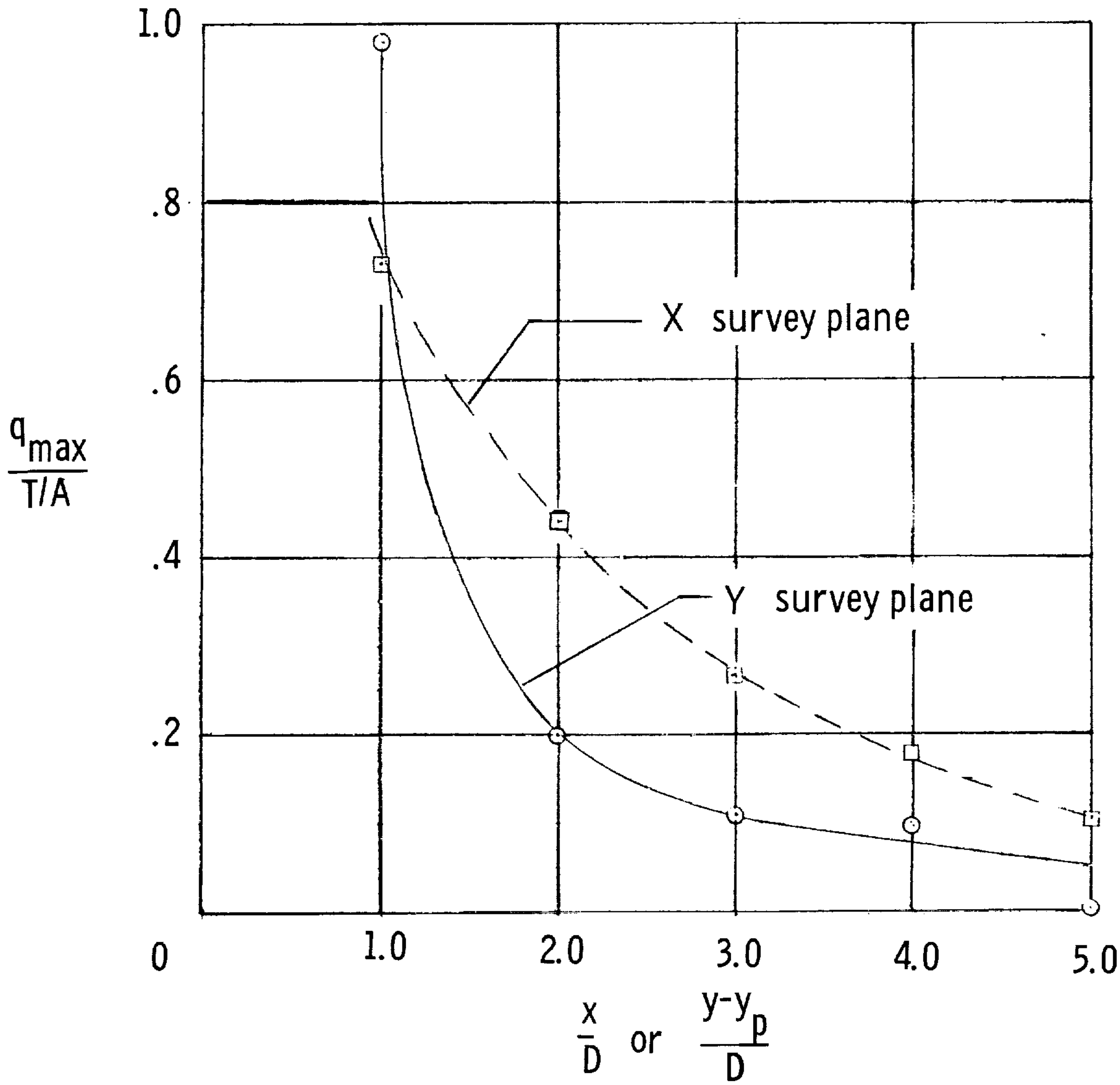

Figure 4.- Variation of maximum dynamic pressure for twin-propeller VTOL aircraft, measured on plane of symmetry and on line normal to fuselage through center of rotation of propellers.

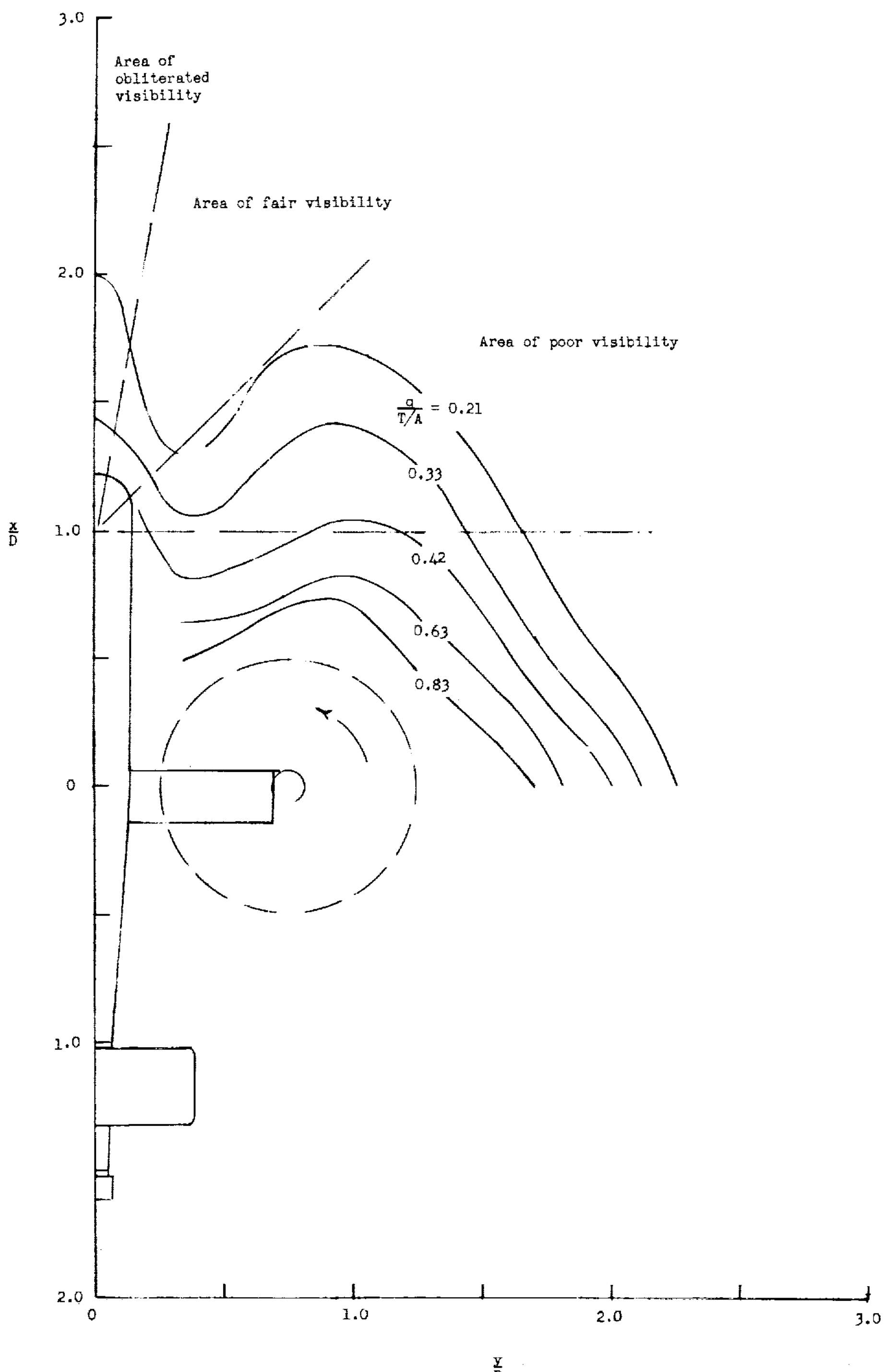

Figure 5.- Lines of constant dynamic pressure measured at ground level about front right quadrant of VTOL aircraft. $T/A \approx 24$.

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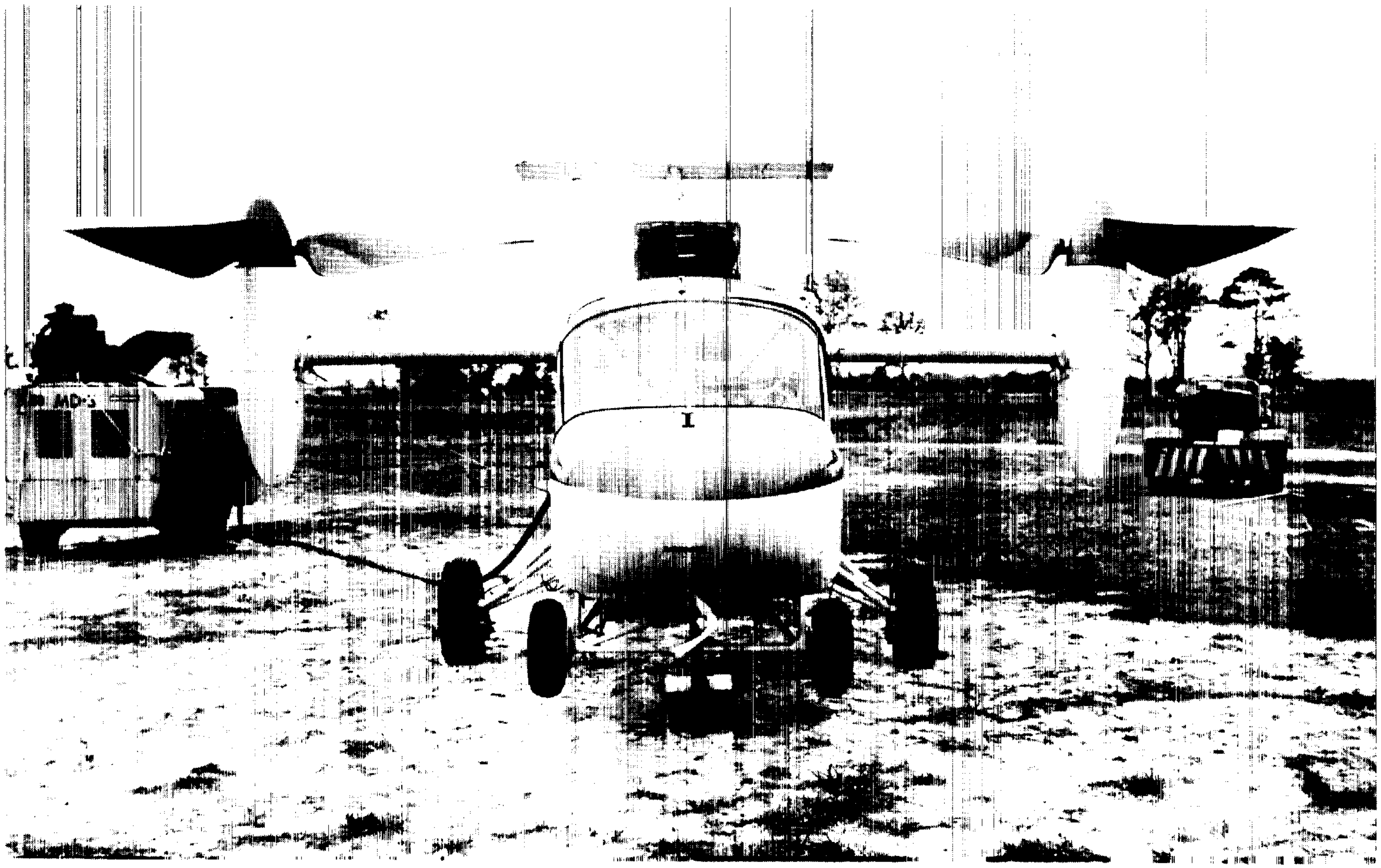


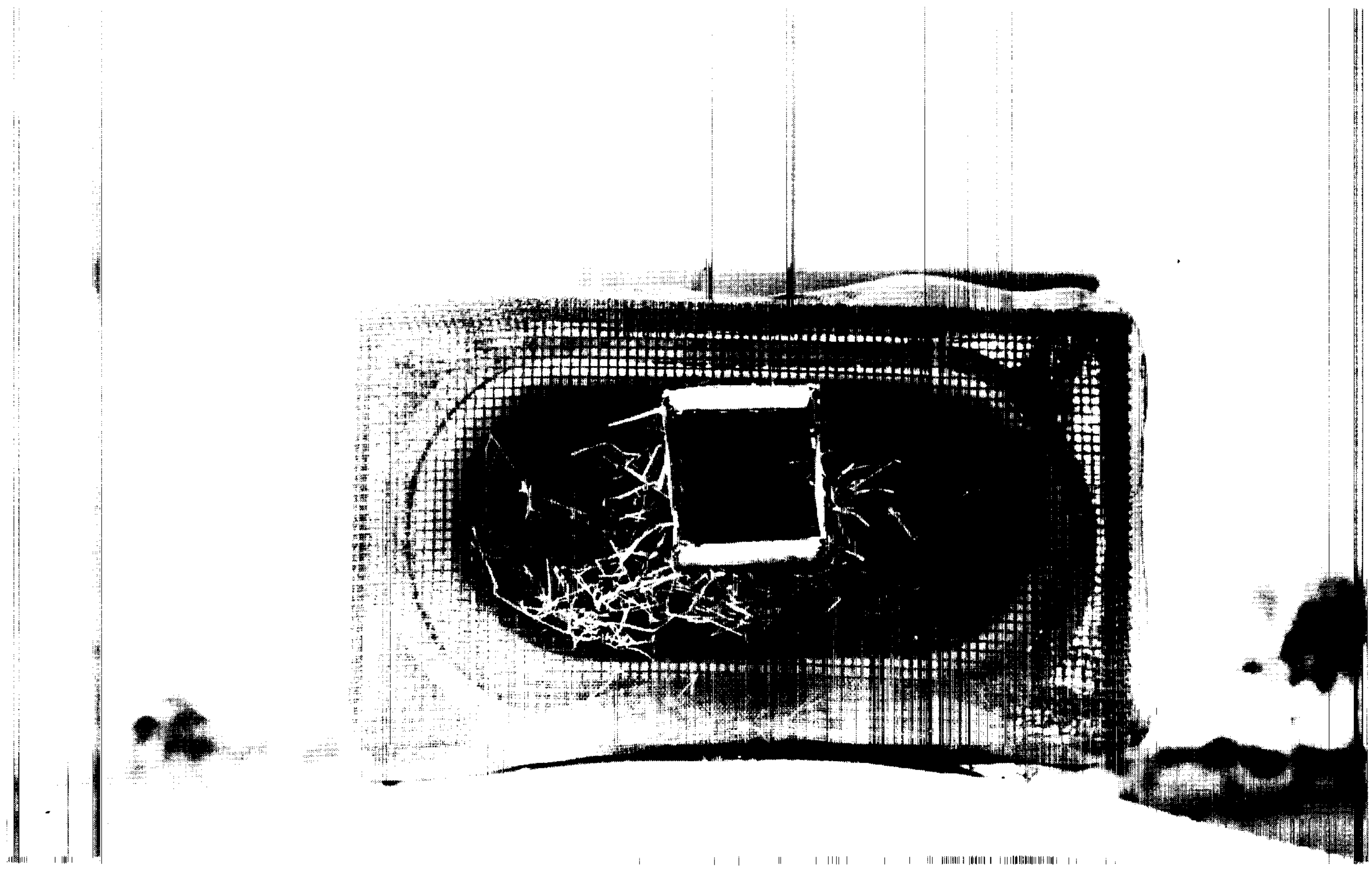
(a) Photograph of aircraft and test site. L-61-2756

Figure 6.- Aircraft operation over relatively bare sandy soil.

L-61-2767

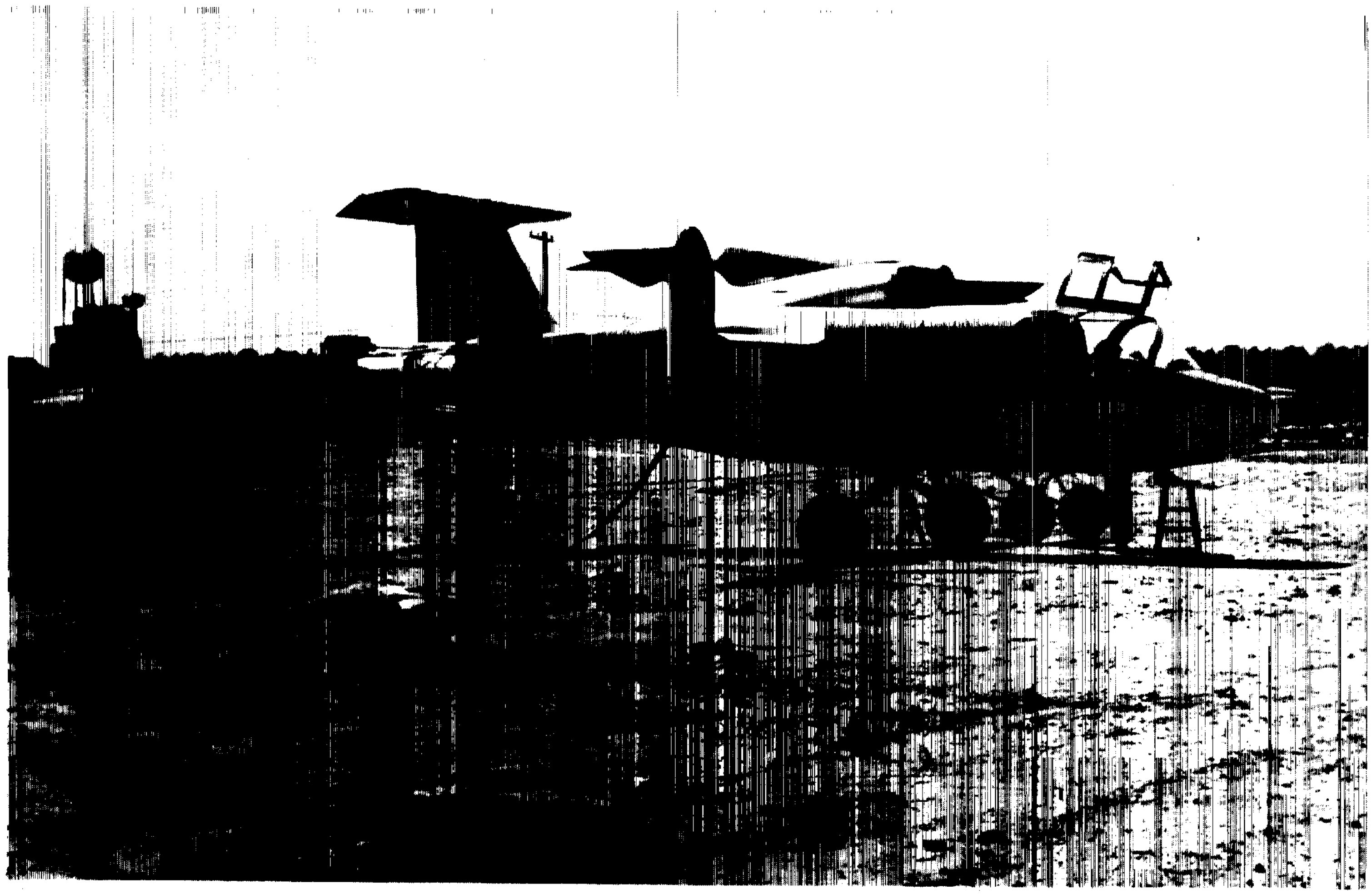
(b) Photograph of typical dirt clods moved by VTOL aircraft downwash.

Figure 6.- Continued.



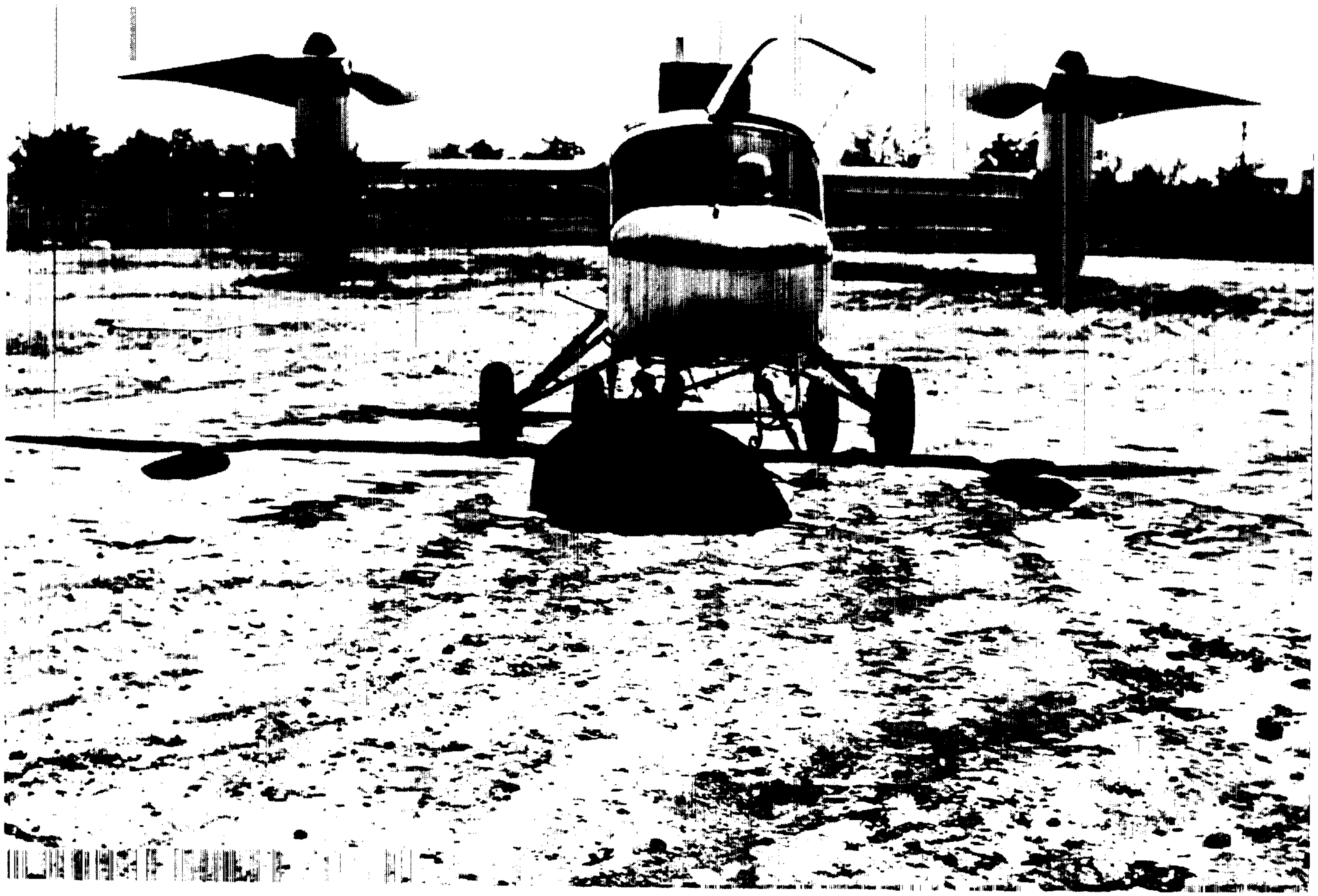
(c) Photograph of air intake screen after completion of test run. L-61-2765

Figure 6.- Concluded.



(a) Photograph of aircraft and test site. L-61-3485

Figure 7.- Aircraft operation over naturally compacted fill dirt.



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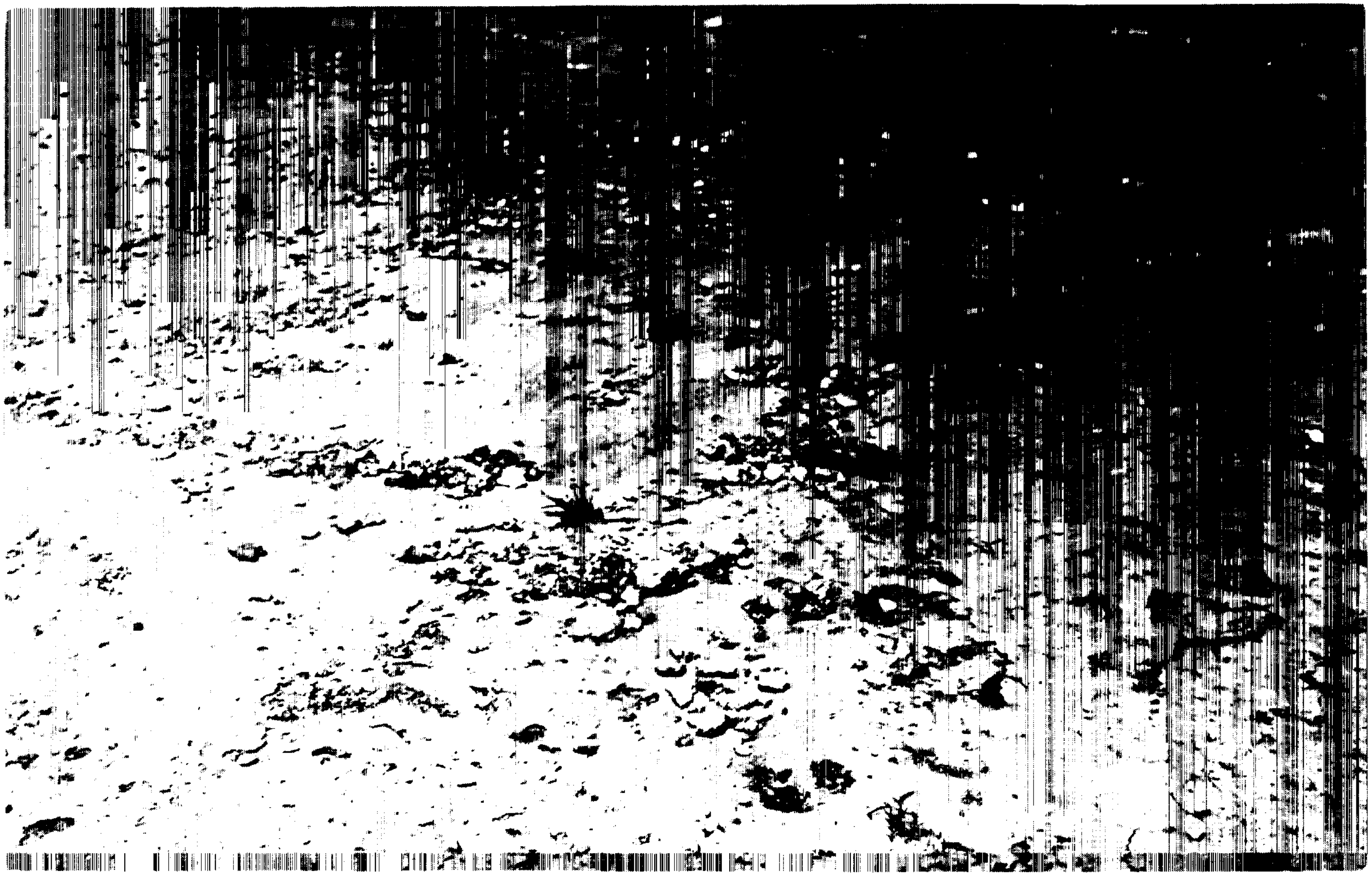
(b) Photograph of typical areas of ground surface peeled away by downwash.

Figure 7.- Continued.

(c) Closeup view of typical peeling of surface. L-61-3490

Figure 7.- Continued.



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(d) Photograph of typical accumulation of gravel produced by action of downwash.

Figure 7.- Concluded.

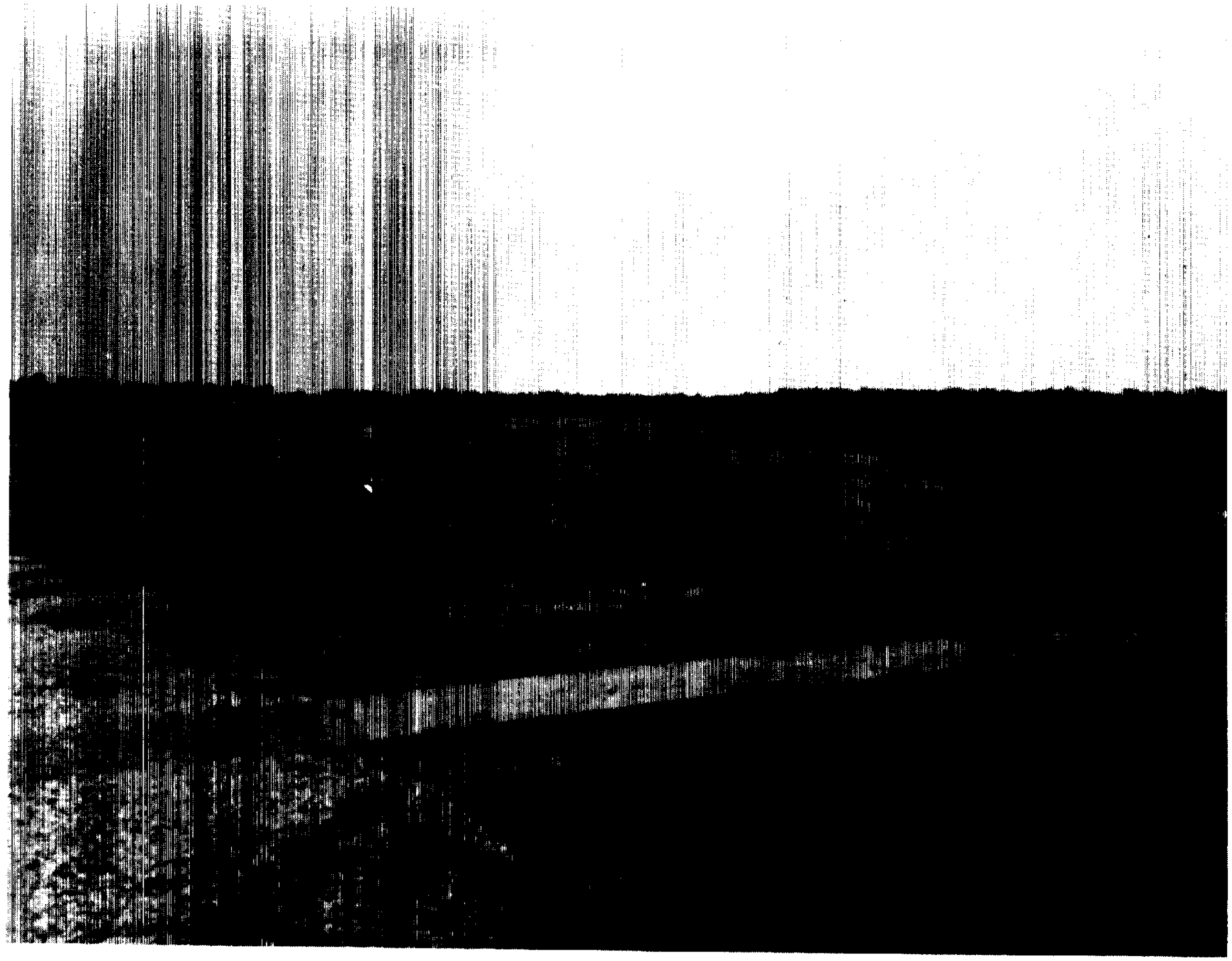

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Figure 8.- Photograph of runway overrun area covered with loose gravel.

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(a) Camber face. L-61-4788

(b) Thrust face. L-61-4781

Figure 9.- Photographs of areas of damage for a typical propeller blade.

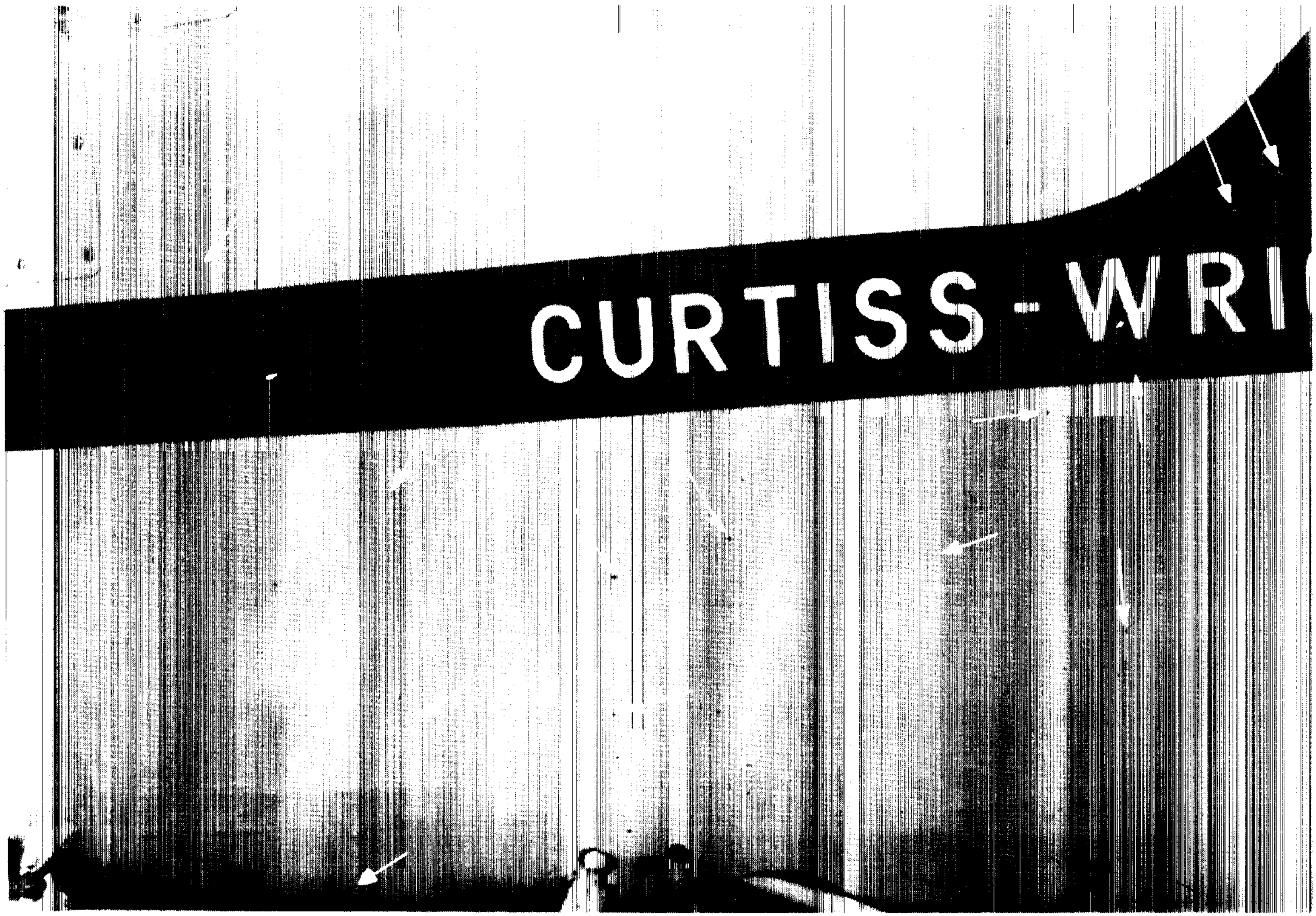

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Figure 10.- Photograph of damage to side of fuselage from movement of gravel.

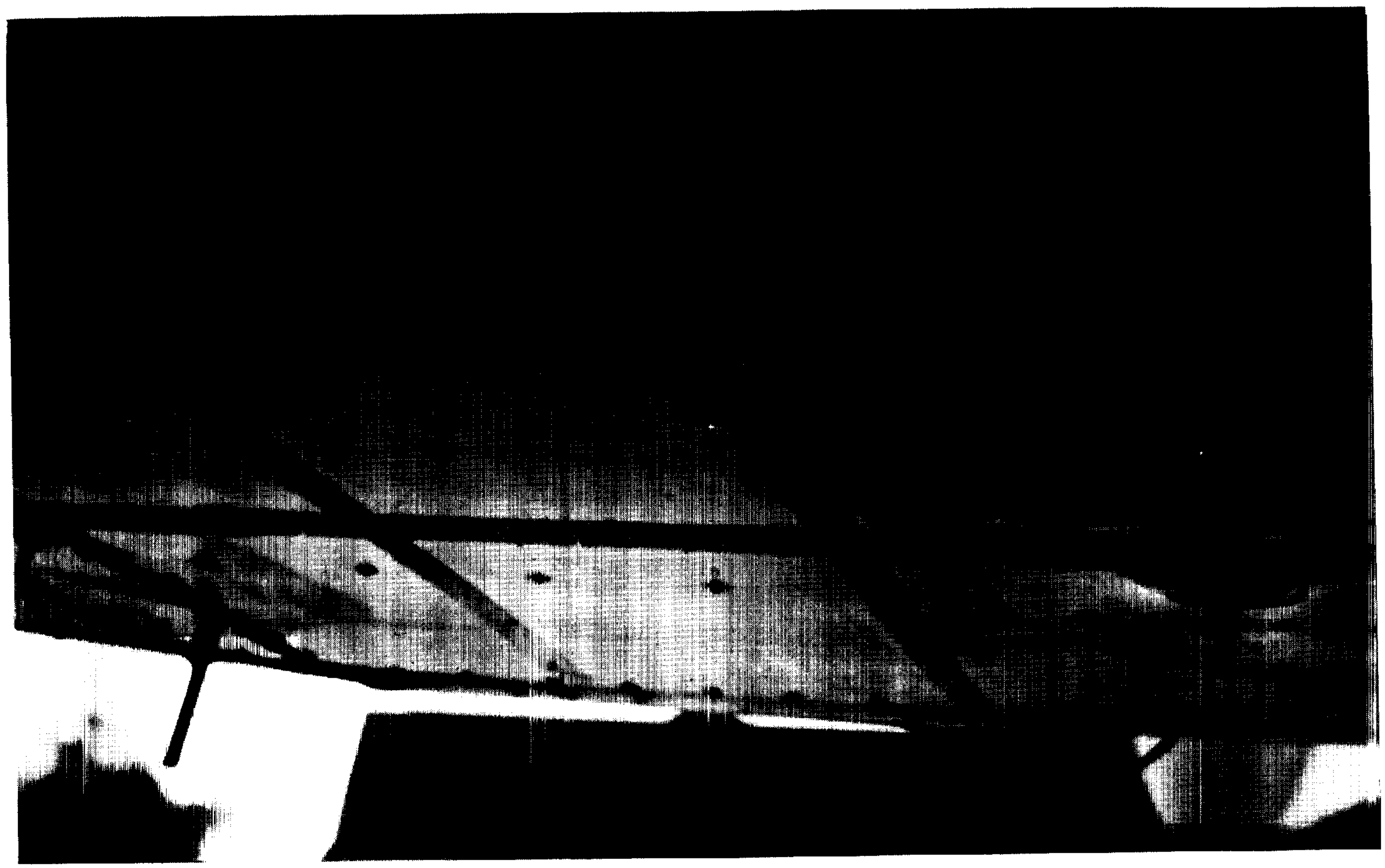

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Figure 11.- Photograph of double-faced masking tape located on bottom of fuselage, showing sand-size particles accumulated during test run.

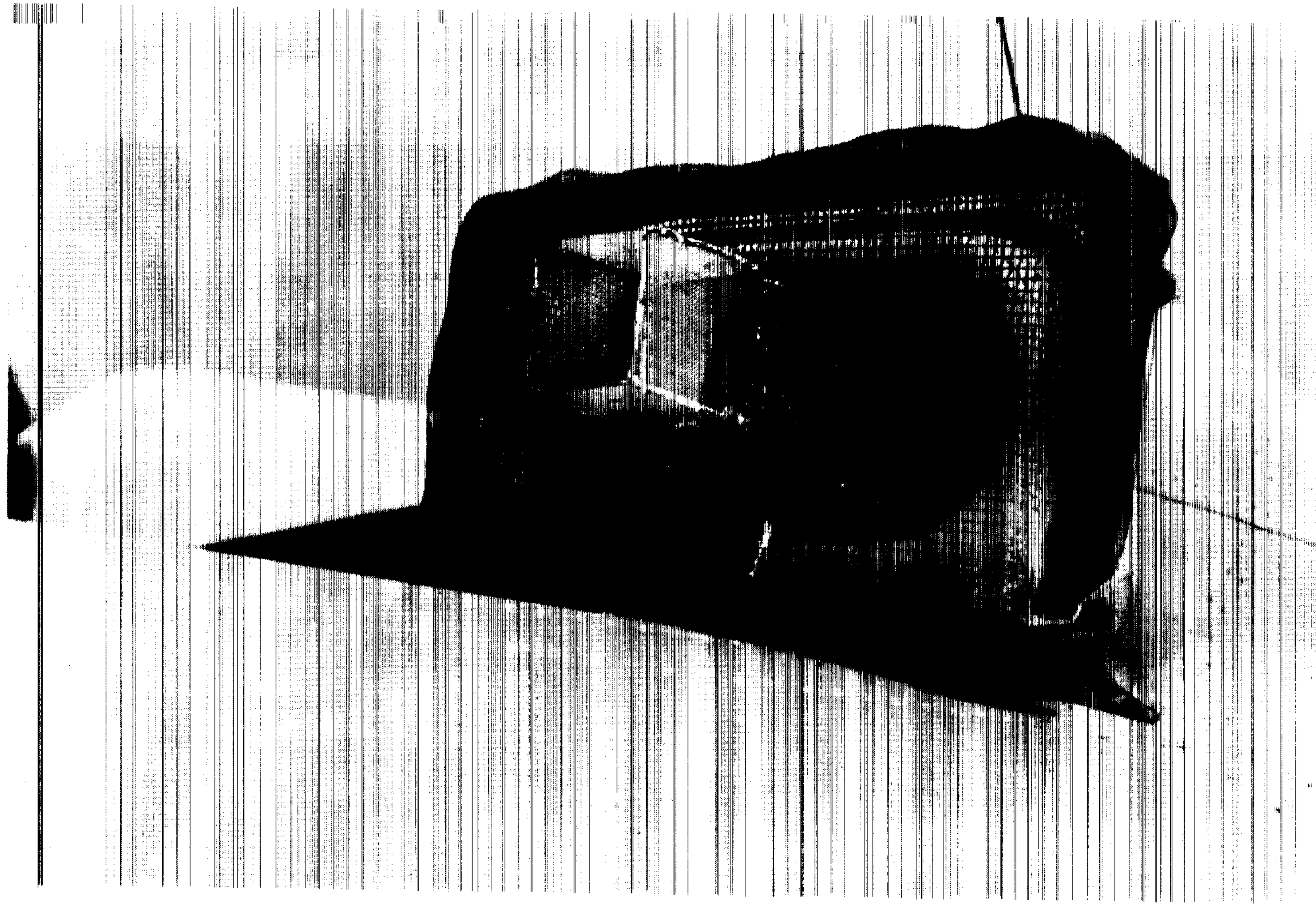

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Figure 12.- Photograph of screened engine air intake upon completion of test run.

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